NOCTILUCENT CLOUDS AND UNPUBLISHED MEASUREMENTS OF THEIR VELOCITY

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In the summer of the year 1885, two years after the volcanic eruption on the island of Krakatoa, between Java and Sumatra, there appeared at different places in middle Europe marvelously bright phenomena in the night sky. The phenomena showed the greatest brightness not far above the horizon, and were observed only at the time of the summer solstice.

The remarkable light phenomena were viewed for the first time in June, 1885; in 1886 they were observed on and after May 28. In the following years they were seen repeatedly from May to the middle of August. We are especially indebted to O. Jesse, who followed the phenomena and determined the height of these clouds, later named "noctilucent," as 82 km.

The importance of the observation of these luminous night clouds lies chiefly in the fact that they can throw light on the conditions of movement in the highest atmosphere, which was possible to be obtained hitherto in extremely limited measure only from observation of meteor trails and the movements of auroras. In an unpublished manuscript, *Die leuchtende Nachtwolken und das widerstehende Mittal im allgemeinem Raum,* O. Jesse assembled everything of importance relative to the noctilucent clouds.

We reproduce here his description of one of the most brilliant appearances of the luminous clouds:

On July 19, 1885, the phenomenon appeared in extraordinary splendor. At Steglitz the sun set in an entirely clear sky. Exactly 15 minutes later there appeared over almost the whole sky detached gray-white streaks that differed not at all from the ordinary cirrus and which, with the further sinking of the sun, spread wider and wider, so that in the course of 10 minutes the whole sky, with the exception of a low segment in the southeast, was filled with them. The arrangement of the individual clouds was extraordinarily regular. The movement was directed from north-northeast to south-southwest; in this direction there lay long, narrow, seemingly parallel streaks, ridges, or polar bands, separated at the zenith by about 12° and gradually converging toward the horizon. On the horizon all of the streaks appeared to unite in one point, and the phenomenon thereby took the appearance of an enormous fan. The spaces between the streaks or ridges were filled with short cross ribs lying, it seemed, exactly at right angles to the streaks and separated at the zenith by about 5°.

At first the color and brightness of the clouds were not striking and the forms were more coalescent than sharply defined.

After a while dissipation, rather slow at first, set in on the southeastern side of the phenomenon, and it was extremely striking that to the naked eye not even the least trace of cloud was visible in the space where obliteration had occurred. With an opera glass it was possible, however, to follow the phenomenon just a little farther toward the darker part of the sky (*Nachthimmel*). As the southeastern limit of the phenomenon passed the zenith the progress of dissipation was considerably more rapid; later it became retarded.

Approximately at the time the southeastern limit was at the zenith there was noted in the northwestern sky a peculiar darkening, which produced an almost uneasy feeling, especially since just previously no trace of dark clouds had shown. From the horizon to an elevation of about 10° the sky appeared entirely black, like a threatening thundercloud, while farther up in the sky the peculiar clouds, which gradually became clearer and brighter with advancing darkness and now stood forth in sharp definition, formed with their light a remarkable contrast with the dark wall on the horizon. Beginning above and gradually extending downward, the light encroached upon this dark wall, and when the upper limit of the noctilucent clouds in the northwest was about 15° the northwestern sky, with the exception of the lowest part about 4° wide, glowed in a splendid sea of light.

In the luminous cloud surface there could be distinguished three horizontal strata. The lowest stratum, hidden in greatest part from the horizon to an elevation of 4° by houses and trees, had a dull reddish-yellow aspect; the second stratum immediately above gave forth a splendid blue-white, silver light; the upper stratum shed a light that was similar but somewhat less brilliant, and stood sharply delineated against the night sky. The boundaries between the strata were not sharp; there was a gradual transition. The contrast shown to the adjacent night sky by the bright middle stratum appeared to be the same as that shown to the immediately adjacent sky by the nearly full moon when it is at an elevation of about 10° in the eastern sky at or just after sunset.

In a manner similar to that observed on this evening the phenomenon manifested itself in the following years, yet from year to year there was a continual decrease in intensity. Moreover, it is to be mentioned that even in the first years it was not very frequently of the same extent and splendor as on this evening. Phenomena of lesser brilliance were rather frequent in the first year, on an average about two or three times in each week.

The noctilucent clouds appear only at the time of the summer solstice and only with clear sky, then not in every part of the sky, but only in the twilight segment. They are not visible, however, on every summer night, when they really might be expected. Despite the continuance of starry nights for 8 to 14 days, it happens that they do not appear, but once visible they remain so for several nights in succession.

In the year 1894 the phenomenon had faded to such an extent that it was observed only rather rarely, about four times during the usual time of its visibility, and then with lessened intensity of light. Cases in which the phenomenon appeared at elevations greater than 6° were very rare.

It is a remarkable fact that the luminous night clouds were to be seen more frequently after midnight than before that hour. In the years 1889–1894 the phenomenon was observed after midnight thirty-three times, but before midnight only six times. Jesse holds it not entirely precluded that even in 1884 noctilucent clouds may have appeared after midnight; he expressly denies this relative to the time before midnight.

The bightness of the noctilucent clouds was always especially marked in the first days of August. On the distribution of the phenomenon over the Northern Hemisphere, Jesse remarks:

In addition to the numerous observations from Germany there are reports from Holland, England, Norway, Denmark, Russia, Austria, and Italy. The zone in which the clouds have been seen extends, therefore, from 45.5° to 61.6° north latitude. In those regions that lie still farther north it appears that there is a specially large accumulation of cloud material, since the phenomenon appears far brighter in the northern regions than in the latitude of Berlin.

The earliest observation of the noctilucent clouds was made by T. W. Backhouse at Kissingen on June 8, 1885.

It has been proven by repeated observations that the phenomenon of noctilucent clouds is due to the sun's illumination of a stratum of foreign matter, which, in latitudes of about 45° to 64°, floats in the atmosphere at a distance of 82 km. from the surface of the earth. That part of the stratum sheltered from sunlight by the earth's shadow is invisible to us, and the phenomenon has been observed only at those times when the sun is below the horizon, so the time of visibility lies within twilight and mainly in the darker part of the same.

The noctilucent clouds are distinguished from the ordinary cirrus, to which they are in some respects rather similar, by their greater brightness. This brightness may be three or four times that of the twilight sky, while the cirrus within the twilight segment stands out dark on the bright background.

The luminous night clouds observed at this time were caused by volcanic masses hurled into the high atmosphere by the eruption of Krakatoa. They were visible south of the Equator also, but only at the time of the summer solstice of the Southern Hemisphere.

On the outward form and movement of the phenomenon Jesse writes as follows:

The variability in the cloud forms is generally great. In the photographs, part of which are separated by an interval of only five minutes, it is a rather rare case that the same cloud points are present in two views. In general the form on the second photograph, although similar to that on the first, is entirely different in detail. I sought to determine the movement of the noctilucent clouds by directing my eye to a definite point. However, it was possible only once in a while to keep the same point with the eye longer than two or three minutes.

When photographs are taken at intervals shorter than two minutes, as by F. S. Archenhold for the purpose of determining movement, corresponding points are, as a rule, present in two views; yet it happens, especially for high elevations, that this is not the case.

The direction of movement of the noctilucent clouds is often variable on different days. It has been possible, however, to ascertain that the movements after midnight are subject in a special way to a definite law, while before midnight this conformity to law appears in a form somewhat different. The velocity is, as a rule, subject to marked changes, but on an average it is greater after midnight than before that hour. After midnight velocities lie between 25 and 200 m.p.s., while before midnight they vary from zero to 85 m.p.s.

The results of measurements given in the tables [1] show remarkable peculiarities with reference to velocity and direction of the noctilucent clouds. Despite the rather large number of observations, movement from south azimuths, from about southeast to southwest, has not been observed. In the phenomena before midnight most movements are from azimuth 48°;[2] in those after midnight from azimuth 63°. In addition, the observations indicate a secondary maximum from azimuth −73°.

For the mean velocity of the clouds there were obtained the values of 31 m. p. s. from west azimuths and 67 m. p. s. from east azimuths. The conformity to law permits conclusions on the movements in the highest strata of the atmosphere, and just here lies the significance of observations on the movements of the noctilucent clouds. During the first years, 1885 to 1887, observations were made in Germany only before midnight and almost entirely with reference to the 16-point wind rose, while in the years 1889 to 1891 and again in 1894 the determinations were carried out almost always after midnight by means of photographs succeeding one another after an interval of about one minute. Although the movement can generally be determined rather well by the latter method, in individual cases the accuracy that is obtained leaves much to be desired. The phenomenon generally remains at low elevations, up to 10°, and in this region the determinations can be only uncertain. However, the rather uniform arrangement of the individual values of a group of observations indicates that the resultant errors are probably not very considerable. It is to be mentioned that all points of a pair of views have been combined for a mean value, so that the uncertainty has been reduced considerably. The distance between the streaks or ridges appears to be always approximately the same. The mean distance between wave lines varies but little from 9.4 km.

Jesse held the opinion that both the seasonal variations in the appearance of the noctilucent clouds and their movements can be readily explained by the assumption of a resisting medium in the space of our solar system. He assumed that this resisting medium is not at absolute rest but takes part in the motion of the solar system. It follows from this that the resisting medium itself must have, like the planets, a direction of motion around the sun. Under this condition there can be, as is actually the case, no manifestation of hindrance to the motions of the planets. Only in the case of the comets, with their great inclinations and partly retrograde motion, may an influence make itself eventually noticeable. At the surface of the earth the atmosphere shares fully in the rotation of the earth, but at the limit of the earth's atmosphere this will no longer be the case; so between the surface and the upper limit of the atmosphere the velocity of rotation will gradually decrease. In the vicinity of the earth this movement is not to be observed, since the meteorological currents are predominant. On the other hand, at elevations of over 30 km. an east-west current appears to prevail.

Let us first consider the velocity which a cloud floating at the limit of the earth's atmosphere will appear to have relative to an observer on the earth. Since in our latitudes the rotational velocity of the earth is about 250 m. p. s. in a west-east direction, then from the viewpoint of the observer the clouds will have an apparent motion at the same velocity, but in the opposite direction.

Since nothing is known in advance of the motion of the outer atmosphere (*Weltraumluft*), several assumptions must be made here. Observations of the noctilucent clouds have shown that the rotational velocity of the earth can be recognized in the movements of those clouds. The other motions of the earth relative to the outer atmosphere (*Weltraumluft*) can be only slight, since if we should take the relative velocity equal to the revolutional motion of the earth around the sun, which is 30 km. per second, the rotational velocity must disappear in contrast. A translatory motion of the earth relative to the resisting medium is, however, not to be left out of consideration, since the observations show a dependence of direction of cloud movement on the solar apex. The noctilucent clouds are not at the limit of the earth's atmosphere, since their average velocity from the east is not 250 m. p. s., as it must be in that case, but only a fractional part thereof. The height of the limiting stratum must be, on the contrary, several hundred kilometers.

Jesse set forth these interesting considerations in detail in his manuscript. As to the nature of the noctilucent clouds, he held the opinion that they are to be referred to gas masses that were hurled aloft by the Krakatoa eruption and have permanently condensed at a constant height.

Later pursuit of the luminous night clouds shows that they have been visible from time to time even after the Krakatoa eruption. Here, also, the phenomena are often to be related with volcanic eruptions. It is possible, moreover, that solar activity possesses an influence over the phenomena. There were numerous large sun spots when the noctilucent clouds were observed in the years 1908, 1917, and 1918. Lately Jardetsky has advanced a new theory. He points to the fact that at about 70 kilometers above the earth hydrogen and oxygen are found in the ratio of approximately 2 to 1 (oxyhydrogen gas). He believes that under the influence of electrons emitted from the sun there form ice crystals which shine with reflected light. In any event, it can be said that the clouds must be attributed to the presence of foreign matter at these heights, hurled there by volcanic eruption, formed there under the influence of solar raditation, or transported there from without. Their connection with twilight anomalies, which occur for the most part after volcanic eruptions, confirms this opinion. At the passage of the earth through the train of Halley's comet in the year 1910 an optical disturbance was plainly noticeable.

The passage through the train of the comet took place during the night of May 18–19, 1910. The twilight disturbances began on May 18 and reached the maximum

[1] Not reproduced here.
[2] Azimuth reckoned from north; positive toward east, negative toward west.

on May 19. Possibly the noctilucent clouds photographed by myself in 1910[3] are to be attributed to foreign matter carried in by Halley's comet.

With the noctilucent cloud at a constant height there exists a relation between the distance of the sun below the horizon and the zenith distance to which the clouds are visible; they remain bright so long as they receive the direct light of the sun. The values for 1910[4] conform to the relation derived by Jesse for noctilucent clouds as well as might be expected.

It may be stated that in this case also the noctilucent clouds had an elevation of some 80 km., although no direct determinations from two stations are available. During the time of photographing, the sky was entirely clear, with no artificial light on the horizon. The direction of the cloud streaks or ridges was northwest to southeast and the direction of movement the same. The west-east component of velocity was somewhat above 20 m. p. s. On July 17, 1910, after a wonderful red sunset, I saw at about 10:05 p. m. noctilucent clouds extending up beyond Capella. At 10:15 p. m. the brightest streak was prolonged in a southerly direction and another streak had become visible to the left and below. After 10:35 p. m. the streaks were no longer visible in the clear sky.

Doctor Korn reported to me by letter on an observation made at the same time. With Lieke he observed at Wongrowitz (52° 48′ N., 17° 22′ E.) on June 24, 1910, at 11 p. m., noctilucent clouds in the north—cirrus forms that shone with silver light up to 1.5° below Capella, which was almost exactly north. From north they extended 15° to the east and 30° to the west. Doctor Korn observed the optical disturbances of May 19–25, 1910.

Information on the years in which noctilucent clouds have been observed is given in *Beiträge zur Kenntnis der Dämmerungserscheinungen und des Alpenglühens* by P. Gruner (Zurich, 1925). There is, however, no reference to the observations in June, 1910.

Since the noctilucent clouds will certainly return, I hope that through the above details the interest in these phenomena will be revived.—*Translated by W. W. Reed.*

[3] 6 reproductions accompany the original text. [4] Table not reproduced here.

NOTES, ABSTRACTS, AND REVIEWS

THE MAGNETIC STORM AND AURORA OF JULY 7–8, 1928

An unusually extensive auroral display was observed over nearly all parts of the country on the night of July 7–8. This display was noted locally from the northern border to the Rio Grande and in central Florida, and from the Atlantic to the Pacific. At many points the display was indicated as being of unusual brilliancy, and its effect on wire communications was distinctly noticeable, some stations reporting that on account of clouds the manifestation was not visible, but its presence was reliably indicated by wire troubles.

In some sections it was reported as being the first auroral display ever observed in a midsummer month. Following are several reports of this auroral display.—*P. C. Day.*

London, England.—A magnetic storm, accompanied by a display of the aurora borealis, took place during the night of July 7 and morning of July 8. The magnetic disturbance reached a maximum between 1 and 2 a. m. on July 8. About this time, also, the horizontal force and vertical force traces went off the recording sheets. The ranges of these two elements exceeded 500 during the storm. This magnetic storm is probably the largest recorded at Greenwich since that of May 13–17, 1921—it is certainly the largest since that of October 15–16, 1926.

At the time of this recent storm there was a moderate-sized group of sunspots just past the sun's central meridian. Possibly spectroscopic observations which may have been made of this group will show it to have been unusual. There was a much larger group on the disk at the time, but this was a considerable distance east of the central meridian. The sun's general activity shown by the spots has been increasing during the last few weeks.—*Nature, London, July 21, 1928, p. 108.*

Worcester, Mass.—I first saw the display at 9 p. m., when it covered virtually the entire sky down to about 10 above the SSE. horizon. This part of the display, from 9 to 9:15, was one of considerable brilliance and was marked not only by its extensiveness and the auroral corona but also by large patches of intense red or green. The exceedingly clear air and sky favored a fine view of the display. Immediately after this bright phase, from 9:15 to 9:30, there were four distinct arches, two overhead and two in the north, while two in the southern sky had faded but could still be distinguished. At 10:15 the display was still extensive but not so bright.

At 10:40 the display was entering on another stage of great brightness, color, and extent. Colors appeared at 10:45, rapidly becoming bright. The greens carried the most light, while the reds, varying from crimson to fire glow, were rich in tone. The display again extended far into the south down to within about 10 of the horizon, the southernmost arch being very bright. The corona formed brilliantly overhead and to the SSE. of the zenith. The total light was sufficient for reading. At 10:52 the display began to flicker. There was considerable motion in the corona.

From 10:55 to 11 a steady, progressive motion of auroral lights across the zenith was noted and roughly measured as to angular velocity. The mean of four observations was 0.1 radian in 10 seconds. At a height of 100 km. this would mean a velocity of 1 km. per second. I assume that this motion may be taken to represent the wind at that great height.—*Charles F. Brooks, Clark University.*

Sheepshead Bay, N. Y., July 7–8, 1928.—I first noticed it at Sheepshead Bay right after sunset, Saturday night, in the form of what appeared to be a vivid greenish yellow cloud of sulphur smoke that suddenly grew in the eastern sky and quickly faded away. A captain of a fishing boat said he also noticed this phenomenon in the eastern sky while the sun was still above the horizon.

At 9:30 there gradually glowed into pronounced brilliance, halfway up in the southern sky, a broad bow of yellowish-white light which stretched completely from the eastern to the western horizon along the ecliptic. At 10 p. m. the characteristic aurora borealis sheets, streamers, bands, and rays, red, green, yellow, white radiated from the zenith to the northeast horizon. It had faded by 11 p. m. with the exception of a few faint rays in the northern sky.

About 2:30 a. m. auroral streamers again began to grow in the northern sky, and by 3 a. m. and until dawn the sky was resplendent with as brilliant an aurora borealis as is seen in this vicinity. It blazed, sizzled, pulsated, seethed, and flashed with an awesome brilliance in all the colors of the rainbow.